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What Does One Know When One Knows How to Improvise?

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ABSTRACT

Cognitive models of improvisation align with pedagogical methods in suggesting improvisers' need for both procedural and declarative knowledge. However, behavioral experiments do not directly address this division due to the difficulty of operationalizing improvisation.

The present study seeks to experimentally demonstrate different types of knowledge involved in producing musical improvisations and to contribute an experimental paradigm.

Ten jazz pianists improvised on a MIDI keyboard over backing tracks. They produced one-handed monophonic improvisations under a 2x2x2 fully factorial design. The conditions contrasted levels of motor familiarity by varying which hand (right vs. left) played which musical function (melody vs. bass line) in which key (B*b* vs. B). MIDI files were analyzed using MATLAB to determine the entropy, the proportion of diatonic pitch classes, the nPVI of a quantized version of the data, and the nPVI of a version left unquantized. Separate ANOVAs compared these values across conditions.

Significant main effects were found between keys and hands. In the key of B, pianists produced improvisations with lower entropy and with more diatonic pitches than in B*b*. The right hand had lower quantized nPVI values than the left hand. Several significant interactions were also found.

This research reframes the distinction between theoretically proposed types of musical knowledge used in improvisation. In unfamiliar motor contexts, pianists improvised with less pitch class variability and more diatonic pitch classes, implying that in the absence of procedural knowledge, improvisers rely more on explicit knowledge of tonality. This suggests new ways to consider modes of improvising.

I. INTRODUCTION

Though cognitive-scientific theories of musical improvisation are few, they generally agree that the behavior engages interrelated types of knowledge (e.g., Pressing, 1988, 1998; Clarke, 1988). What a musician needs to know to improvise is not just explicit knowledge of scales, harmonies, and chord progressions, but also implicit knowledge of motor patterns – so called 'muscle memory'. It is not clear, however, how to distinguish between these types of knowledge. It is intuitive to make some kind of distinction between ways of knowing, but it is difficult to know where and how to draw that line and whether it is feasible to draw such a line at all. Further, there are many problems with trying to study musical improvisation in the laboratory, mostly stemming from the inherent (and welcome) variability of such a behavior. This study proposes an experimental method along with a set of analytical techniques which together can serve to demonstrate characteristics of different types of knowledge employed by improvising jazz pianists and which can clarify the theoretical distinction and relationship between these ways of knowing.

II. BACKGROUND

This research question can be refined by considering different approaches to learning jazz piano and proposing an initial distinction between ways improvisers understand musical structure. Sudnow (1978) has written an account of how he learned to play jazz piano as an adult. He emphasizes learning the 'feel' of chords and scales. By contrast, a jazz piano student may practice licks and chord progressions in all twelve keys, such as is advocated by Hearle's (1978) method among others. These students may be inclined to think in terms of scale degrees when voicing chords or playing melodic lines.

This comparison is not to suggest jazz pianists only use one or the other approach to knowledge of musical structures while improvising. Understanding musical structure is not only about shapes of the hand or knowledge of scale degrees and chord progressions. Students of either pedagogical method have some knowledge of each type. The point of making the distinction between the 'feel' type of knowledge and knowledge of scale degrees is that it opens this theoretical distinction to experimentation.

What happens when improvisers are forced to improvise in unfamiliar motor contexts when they are unable to rely on familiar motor patterns? How does this affect their access to knowledge of musical structure, and thus the musical content of their improvisations? How would an experiment following from these questions help describe the nature of knowledge of musical structures possessed by improvisers and how types of knowledge may be related?

Pianists can be made unfamiliar with the motor context in which they improvise in two ways. First, playing in keys uncommon to jazz styles (such as B Major) changes pianists' familiarity of the key layout. Pianists would not be able to use motor patterns they have learned to use in a familiar key (such as B*b* Major) to produce the same tonal relationships in this unfamiliar key. Secondly, because pianists can play with either hand, one hand at a time, motor context can be made unfamiliar if pianists improvise with an unfamiliar hand. While jazz pianists typically use their hands together in cooperation, they usually use their right hands to play melodic lines and their left hands to play bass lines. By improvising melodies with their left hands, or bass lines with their right hands, the motor context becomes unfamiliar as different motor patterns would have to be executed to produce the same musical content. These two methods of manipulating the motor context form the basis of the method for the present experiment.

III. PREVIOUS RESEARCH

Studies of the cognition of musical improvisation are relatively small in number. These studies follow a few general strategies for experimenting with improvisation within the laboratory. Participants may be asked to compare improvisation with rehearsed performances through listening to different recordings. In these studies, experimenters aim to determine cues or qualities present in improvisations that may distinguish them from rehearsed performance (e.g., Lehmann & Kopiez, 2010). Neuroscientific research has compared neural correlates of improvisation vs. rehearsed or memorized performance (Bengtsson et al., 2007; Berkowitz 2008, 2010; Limb & Braun, 2008). Also from the neuroscientific literature, Engel & Keller (2011) examined the brain's sensitivity to spontaneity of keystroke intensity and timing, as would occur in improvisations. Developmental studies have examined improvisatory skills at different ages to help determine the necessary cognitive capacities to improvise (e.g., Kiehn, 2003; Guilbault, 2004; Brophy, 2005; Paananen, 2007; see Ashley, 2009 for a review). Lastly, some researchers have developed analytical methods to consider the cognition of improvisation through examining transcribed improvisations such as Järvinen (1995) who analyzed the pitch class content of Charlie Parker solos and a further study on these solos in which Järvinen & Toiviainen (2000) looked specifically at the pitch content as it varied with metrical placement.

The crucial way the present study differs from previous research is that adult participants in a within-group experimental design improvise within the laboratory, and improvisations are compared to other improvisations produced under different conditions instead of being compared to rehearsed performance. Therefore, this is not a study of what makes something improvisatory. Rather, it aims to explore how the cognition of improvisation works by experimentally manipulating the hypothetical types of knowledge employed by improvisers.

IV. HYPOTHESES

Improvisations produced under unfamiliar vs. familiar motor contexts should vary systematically. Under unfamiliar motor conditions, improvisers will not be able to rely on the well-rehearsed patterns and structures used in familiar motor conditions. This should decrease the overall variety of licks and patterns used, thus making the improvisations more predictable. Also, if the musicians rely on their theoretical knowledge of scale degrees in the absence of familiar motor patterns, the improvisations produced in unfamiliar motor contexts will be less chromatic as the musicians will be relying more heavily on chord tones and pitch classes in the diatonic scale. Eliminating access to familiar licks and patterns may also eliminate the rhythmic variability that goes along with them. Subtle variations in rhythmic inflection may be lost as well and there may be less variety in conceptual rhythmic patterns. Three analytical metrics are used to test these hypotheses, described below.

V. METHOD

Ten jazz pianists (ages: μ = 24.3, σ = 4.92, all male, nine right handed) participated in the study. The pianists were either students or recent graduates from the jazz piano program at the Birmingham Conservatoire in the United Kingdom. One participant was a jazz pianist reading music at the University of Cambridge and one was a jazz pianist from a university in the United States. Participants were thus matched for age and musical-educational experience. All participants from these institutions volunteered to participate after receiving an invitation from the author.

Participants were asked to improvise over backing tracks under varying conditions. The backing tracks were taken from a volume of Jamie Aebersold's (2000) "Play-A-Long" series. These backing tracks are audio tracks of a pianist comping, a drummer playing a swing pattern, and a double bass player playing a walking bass line. The Rhythm Changes track was used for this experiment, following the chord progression of the jazz standard *I Got Rhythm* by George and Ira Gershwin (1930). These chord changes are widely used in jazz improvisation.

The recording was originally in B*b* Major, a very common key for Rhythm Changes. An otherwise identical version in B Major was created by digitally transposing the original track up a semitone using Logic Pro's Time-and-Pitch Machine. A version of the track in either key was also created without the bass line. The original tracks are recorded in stereo such that panning one way silences the bass line. Thus, no digital alteration or distortion was necessary to remove the bass line. There were thus four types of stimuli – a version with and without the bass line in either key.

Participants improvised over a total of 40 separate choruses of Rhythm Changes, producing a total of approximately 45 minutes of improvisation each. Before each chorus, participants heard a recording of the experimenter's voice saying which hand to use (right or left), in which key to play (B*b* or B), and which 'function' to play (melody or bass line). For the trials in which the participants improvised bass lines, one of the recordings (in the appropriate key) with the bass line removed was used. Participants were further instructed to play with only the hand specified and not to play more than one note at a time so that the improvisations were monophonic. For the melody condition, participants were advised to consider it as a solo horn line, and for the bass line condition subjects were advised to consider it as a walking bass line and not a bass solo. Also, pianists were advised that they were not limited to the bass register for left hand melodies, and were asked to sit comfortably so as not to contort their posture when they played in higher registers with their left hands and lower registers with their right hands.

There were thus eight conditions (three factors with two levels each). Each condition occurred five times. Trials were organized in a quasi-random order such that no two identical conditions were allowed to occur in succession. After 20 choruses, subjects took a short break before completing the remaining 20 choruses.

Participants used an 88-key weighted MIDI keyboard. The backing tracks were played through headphones using Logic Pro, and MIDI data was gathered also using Logic Pro. The MIDI controller was assigned to the "Yamaha Grand" sound from Logic Pro's instrument library.

In addition to the improvisation task, subjects completed a questionnaire about their musical background and education, age, gender, and handedness. This questionnaire served to guide an interview which followed the improvisation task wherein participants were asked about their musical education in detail, including methods they have used to study improvisation, as well as questions about how it felt to improvise under these unfamiliar experimental conditions.

VI. DATA ANALYSIS

Three types of metrics were used to analyze and interpret the data according to the hypotheses.

A. Entropy

Entropy was used to assess the overall melodic predictability of the improvisations. The jazz pianists chose notes from a set of twelve possible pitch classes. The formal equation for calculating entropy is

$$H = -\sum_{i}^{n} p_i * log_2(p_i)$$

where *H* is the entropy (in bits) of a sample, *n* is the number of elements in the set (in this case, twelve different pitch classes), and *p(i)* is the probability of a particular pitch class from the set occurring within the sample.

Different samples of music have different distributions of pitch class probabilities, and thus the entropy value varies between the minimum entropy where all the pitch classes would be the same (0 bits) and the maximum possible entropy where all pitch classes are used equally ($\approx$ 3.58 bits). A higher entropy value measured from an improvisation is taken to mean a larger amount of variation between the uses of pitch classes. This could imply a larger amount of harmonic flexibility, and a greater variation in melodies and licks. It is an index of musical predictability.

The familiarity of the motor context will likely affect the entropy value as unfamiliar motor contexts may cause improvisers to rely more on a smaller subset of pitch classes.

Entropy has several precedents as a metric in other music studies. It was introduced to music theory by Youngblood (1958) and developed by Knopoff & Hutchinson (1983), who discussed the suitability of using entropy as a metric for comparing composers' styles in the classical canon. More recently, Eerola et al. (2002) correlated a continuous entropy value as a piece progressed with listeners' continuous ratings of melodic predictability. Entropy has also been used to assess variability and predictability of musical features besides pitch classes such as key-stroke velocities as in the Engel & Keller (2011) study mentioned above.

B. Diatonic Probability

A second way to analyze these improvisations is to simply assess the probability that a pitch class is diatonic. This can be measured by expressing a ratio between diatonic pitches and total pitches used in the improvisation. Improvisations may vary in how much they rely on diatonic pitches depending on the familiarity of the motor context.

C. Quantized and Unquantized nPVI

nPVI, the normalised Pairwise Variability Index, is an index of durational variability between events. It was originally used in linguistics (see Grabe & Low, 2002). It has become commonly used in music analysis, as well (e.g., Patel and Daniele, 2003). The nPVI metric could be used to assess rhythmic variability in improvisations produced under familiar vs. unfamiliar motor contexts both before they are quantized (to assess the variability introduced by subtle rhythmic inflections) and after they are quantized (to assess different amounts of variation in conceptual rhythmic organizations).

VII. RESULTS

A total of 400 MIDI files (40 per subject) were extracted from the Logic Pro recordings. The MIDI files were processed in MATLAB using the MIDI Toolbox developed by Eerola & Toiviainen (2004). The pitch class distribution was calculated for each trial. The nPVI values were calculated from each trial using an unquantized version, a version quantized at the semiquaver triplet level, and a version quantized at the semiquaver level.

The pitch class probabilities from each improvisation were used to calculate entropy (measured in bits). The probability distribution of the pitch classes was also summarized into diatonic pitches and non-diatonic pitches so that each MIDI file had a value for the probability that a note would be diatonic. Each participant therefore had 40 MIDI files, each with an associated entropy value, diatonic pitch probability, two quantized nPVI values, and an unquantized nPVI value. (The two levels of the quantized nPVI values returned the same statistically significant effects, so only the semiquaver level statistics are reported here.)

A total of five MIDI files were discarded from the analysis because participants made errors such as playing a left hand trial with their right hand. For each category of the data analysis, this missing data was replaced with averages across all conditions of the rest of that participant's data.

The number of notes in each MIDI file varied (μ = 167.4, σ = 46.4), but because the note counts were all on the same order of magnitude, the metrics for each MIDI file were taken to be equally representative for the purposes of ANOVA.

For each metric, on all the values calculated from the improvisations, a three-way repeated measures ANOVA was conducted with the independent variables *HAND* (2 levels; right and left), *KEY* (2 levels; B*b* and B) and *FUNCTION* (2 levels; bass line and melody). The error bars on all of the following figures indicate one stand error in either direction.

A. Entropy

There was no main effect of *HAND* or *FUNCTION*, but a highly statistically significant effect of *KEY* ($F_{(1,9)}$=40.194, $p<0.001$, η^2=0.817, Greenhouse-Geisser correction applied). The improvisations in the familiar key, B*b*, had higher entropy values than those in B (see Table 1 and Figure 1). There were no significant interactions.

Table 1. Entropy Values by Key

Estimated Marginal Means		
Key	Mean	Std. Error
B	3.230	.042
Bb	3.318	.039

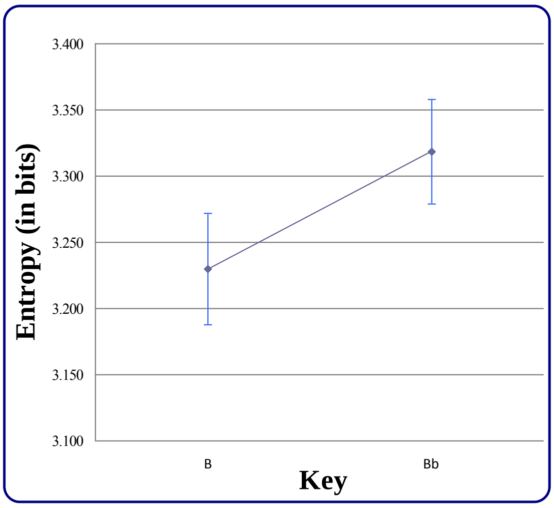

Figure 1. Graph of Entropy Values by KEY

B. Diatonic Probability

There was no main effect of *HAND* or *FUNCTION*, but a highly statistically significant effect of *KEY* ($F_{(1,9)}$=124.465, p<0.001, η^2=0.933, Greenhouse-Geisser correction applied). In the unfamiliar key, B, the improvisations had higher probabilities of diatonic pitches than when playing in B*b* (see Table 2 and Figure 2).

Table 2. Diatonic Probability by Key

Estimated Marginal Means		
Key	Mean	Std. Error
B	0.803	0.016
Bb	0.750	0.016

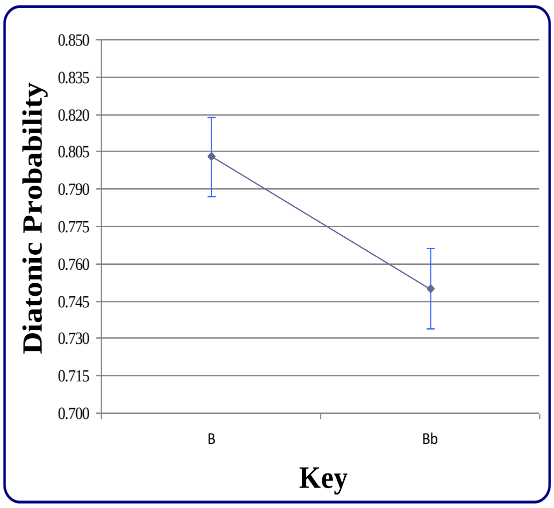

Figure 2. Graph of Diatonic Probabilities by KEY

There were two significant interactions. The interaction between *KEY* and *FUNCTION* was highly significant ($F_{(1,9)}$=32.100, p<0.001, η^2=0.781, Greenhouse-Geisser correction applied). The key of the improvisations had a greater effect on melodies than on bass lines (see Table 3 and Figure 3).

Table 3. Diatonic Probability Interaction between KEY and FUNCTION

Estimated Marginal Means			
Key	Function	Mean	Std. Error
B	Bass Line	.796	.019
	Melody	.811	.018
Bb	Bass Line	.756	.018
	Melody	.744	.019

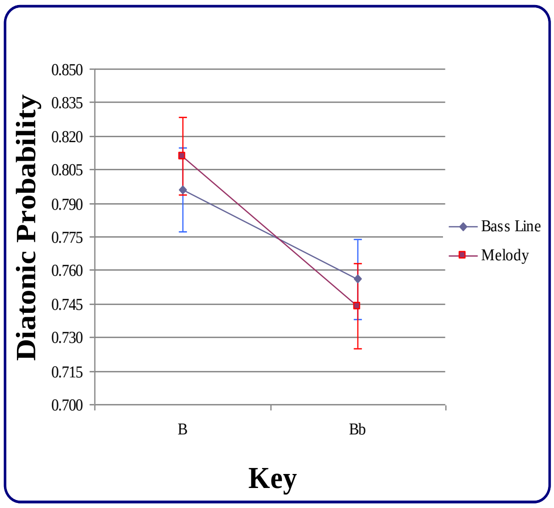

Figure 3. Graph of Diatonic Probability Interaction between by KEY and FUNCTION

A three way interaction between *HAND*, *KEY*, and *FUNCTION* was also significant ($F_{(1,9)}$=5.206, p=0.048, η^2=0.366, Greenhouse-Geisser correction applied). (See Table 4 and Figures 4 & 5.)

Table 4. Diatonic Probability Interaction between HAND, KEY and FUNCTION

Estimated Marginal Means				
Function	Hand	Key	Mean	Std. Error
Bass Line	Left Hand	B	0.802	0.018
		Bb	0.752	0.018
	Right Hand	B	0.790	0.021
		Bb	0.760	0.019
Melody	Left Hand	B	0.809	0.018
		Bb	0.751	0.017
	Right Hand	B	0.812	0.018
		Bb	0.736	0.023

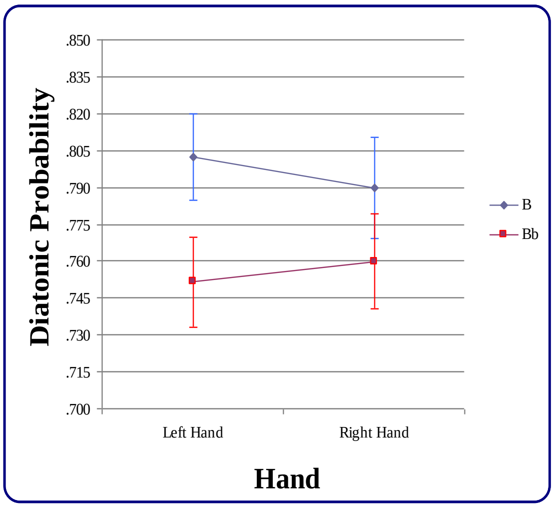

Figure 4. Graph of Diatonic Probability Interaction between by HAND and KEY at FUNCTION = Bass Line

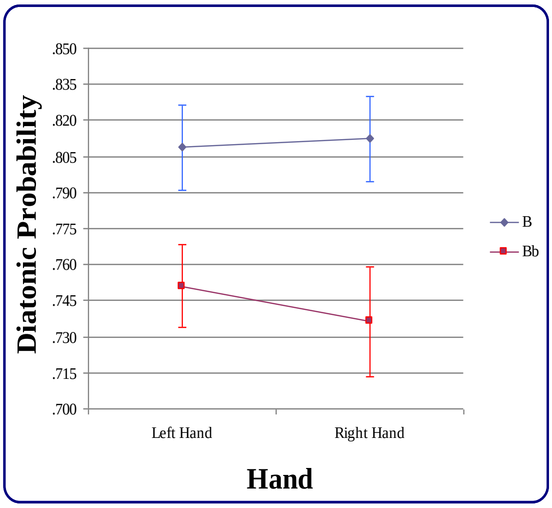

Figure 5. Graph of Diatonic Probability Interaction between by HAND and KEY at FUNCTION = Melody

C. Quantized and Unquantized nPVI

For the semiquaver quantized nPVI metric, there were no significant main effects for *KEY* or FUNCTION. There was a significant main effect of *HAND* ($F_{(1,9)}$=9.577, p=0.013, η^2=0.516, Greenhouse-Geisser correction applied). The right hand improvisations had significantly lower quantized nPVI values than the left hand (see Table 5 and Figure 6).

Table 5. nPVI Value for Quantized Data by HAND

Estimated Marginal Means		
Hand	Mean	Std. Error
Left Hand	38.760	2.516
Right Hand	35.870	2.329

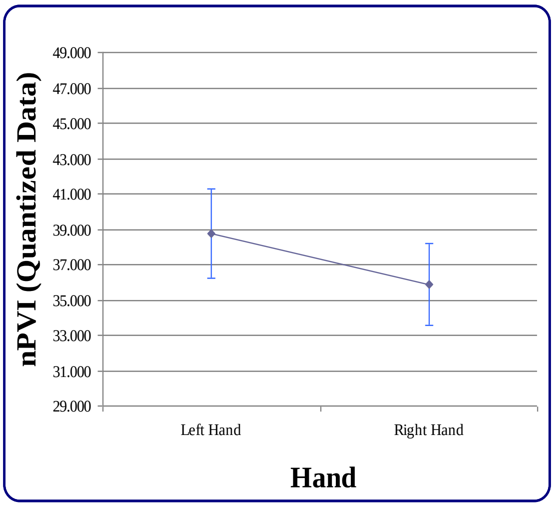

Figure 6. Graph of nPVI Value for Quantized Data by HAND

There was a significant interaction between *HAND* and *FUNCTION* ($F_{(1,9)}$=8.569, p=0.017, η^2=0.488, Greenhouse-Geisser correction applied). Which hand was used had a greater affect on melodies than on bass lines (see Table 6 and Figure 7).

Table 6. nPVI Value for Quantized Data Interaction between HAND and FUNCTION

Estimated Marginal Means			
Hand	Function	Mean	Std. Error
Left Hand	Bass Line	36.984	4.263
	Melody	40.536	1.713
Right Hand	Bass Line	37.502	4.402
	Melody	34.239	2.341

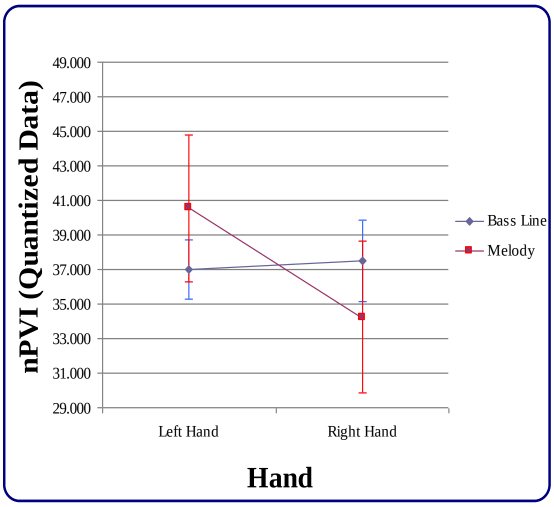

Figure 7. nPVI Value for Quantized Data Interaction between HAND and FUNCTION

For the unquantized nPVI metric, there were no significant main effects. There was a significant interaction between *HAND* and *KEY* ($F_{(1,9)}$=12.558, p=0.006, η^2=0.583, Greenhouse-Geisser correction applied). Which hand was used had a greater effect on improvisations in B*b* than on improvisations in B (see Table 7 and Figure 8).

Table 7. nPVI Value for Unquantized Data Interaction between HAND and KEY

Estimated Marginal Means			
Hand	Key	Mean	Std. Error
Left Hand	B	42.876	3.016
	Bb	41.325	3.307
Right Hand	B	43.832	3.587
	Bb	43.887	3.748

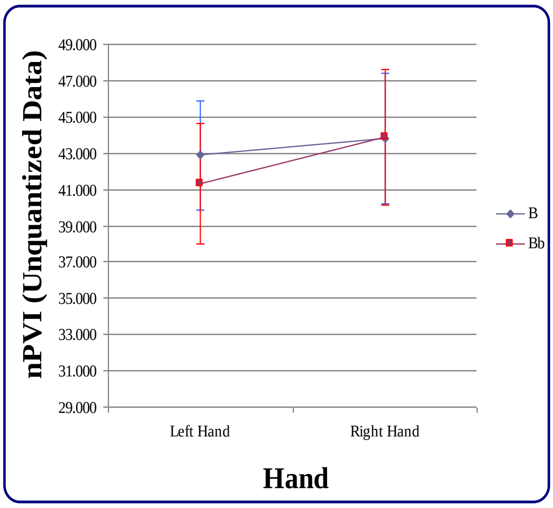

Figure 8. nPVI Value for Unquantized Data Interaction between HAND and KEY

D. Interview Transcripts

Audio recordings of the participants' interviews were made and transcribed. These transcripts helped evaluate the legitimacy of the experimental method and confirmed some of its assumptions (such as that B was an unfamiliar key). Several potential issues with the method were raised by the participants and are addressed below.

VIII. DISCUSSION

A. Main Effects for Key

There were significant main effects between key conditions. The familiar key, B*b*, showed significantly higher entropy and significantly lower diatonic probability than the unfamiliar key, B.

Concerning the diatonic probability metric, these findings confirm the hypotheses. In the unfamiliar key, the pianists used more diatonic pitch classes. In this unfamiliar motor context, pianists would not have access to the procedural knowledge of complex chromatic licks they might employ in the familiar key. They are replaced by a greater reliance on diatonic pitch classes suggesting that pianists are relying on their harmonic understanding of scale degrees and chord tones.

The entropy metric shows that the overall variability of pitches used was greater in the familiar key, and thus the improvisations were less predictable with regard to pitch classes. This suggests that in familiar motor contexts, the pianists are able to rely on a greater and more varied repertoire of figurations and harmonic relationships, evidently dependent on motor programs specific to the motor context.

B. Key Interaction Effects

There was a significant interaction between key and function for the diatonic probability metric. The bass lines, overall, were less affected than the melodies, which had fewer diatonic pitches in the familiar key. Bass lines are typically more limited in their note choices anyway, and are more likely, functionally speaking, to use chord tones and thus diatonic pitch classes. In either key, the pianists were able to play these chord tones in the bass lines, indicating that this information is accessible even in an unfamiliar key. In the melody condition, B*b* had fewer diatonic pitches than B. This, again, suggests that in the unfamiliar motor context imposed by the key layout of B, pianists rely on theoretical knowledge of scale degrees and chord tones, increasing the probability of diatonic pitch classes occurring.

There was a three way significant interaction for the diatonic probability metric. For bass lines, the left hand showed more of a difference between the keys than the right hand. For melodies, the left hand showed less of a difference between keys than the right hand. This is in line with the hypotheses. The right hand shows a difference between the familiar and unfamiliar keys for melody while since the left hand is unfamiliar with either key when playing a melody, it shows less of a difference. For bass lines, the reverse is true. The right hand is unfamiliar with either key, so it shows less of a difference while the left hand is familiar with one of the keys and not the other, so it shows a greater difference.

C. Main Effects for Hand

No statistically significant differences in the diatonic probability, entropy, or unquantized nPVI were found between the hands. There was a significant difference between the hands for the quantized nPVI data.

Pertaining to the diatonic probability and entropy metrics, this could be because the analysis was too blunt to detect a difference between the hands with regard to pitch class choices. The hand conditions may have produced equal values, but for different reasons. The left hand could have simply been using different musical patterns than the right hand resulting in the same diatonic probability or entropy. For example, while the right hand may have been choosing non-diatonic pitch classes from extensions of the harmonies in the chord progression, the left hand may have been relying on chromatic scales, simply guessing which notes to play, or 'taking more risks'. While it may be that there is no difference between the hands in pitch class choices, a sharper analysis which could account for these different ways of achieving the same value might still reveal that pianists were relying on theoretical knowledge of scale degrees and chord tones while improvising with their left hands.

Alternatively, an additional experiment could investigate potential differences not detected by the analytical metrics. One possible experiment to this end would be to ask experienced listeners to subjectively rate how 'jazzy' and musical the left hand improvisations sound. Particularly with the melodies, the pianists may be using equal amounts of chromaticism, but the chromaticism they use might not be used as carefully within stylistic constraints.

Pertaining to the nPVI results, the hand conditions were significantly different using the quantized data, but not the unquantized data. The quantized nPVI can be taken to represent conceptual rhythmic organization and not the variability from inflection present in the unquantized data. Contrary to the hypothesis, the left hand had a larger amount of rhythmic variability. When improvising with the right hand, the participants could have relied on fast runs and passagework which would have low rhythmic variability, and thus lower the nPVI measure. The left hand instead may have relied on rhythmic content (accessible to either hand) in the absence of this technical fluidity.

D. Hand interaction effects

There was a significant interaction between hand and function for the quantized nPVI data. The hands play with similar rhythmic variability when playing bass lines, but the left hand has greater variability when it plays melodies than the right hand. However, the unquantized nPVI showed no significant interaction between hand and function. This contradicts the hypothesis that the right hand would not have the rhythmic inflections of the left hand in bass lines. They are not statistically significantly different. However, similar to the pitch class analyzes between the hands, the nPVI metric may simply not be detecting such a difference. A similar experiment of subjective evaluation of bass line ‘groove’ could potentially address this question. Listeners could rate whether right hand bass lines ‘groove’ as well as left hand bass lines.

The unquantized nPVI data showed a significant interaction between hand and key. The right hand had roughly equal unquantized nPVI values for either key, but the left hand had a higher nPVI value for the unfamiliar key. The hypotheses predicted that unfamiliar keys for either hand would influence the rhythmic variability, but the evidence here suggests the right hand is unaffected by the key while the left hand is affected. Even though the unfamiliar key has more diatonic pitch classes in the improvisations, the right hand may have been able to play the same rhythmic patterns for melodic and bass line patterns while the left hand, unable to play fluently in the unfamiliar key, interpolated more varied pauses or perhaps relied on rhythmic motives more generally in the absence of passage work with notes of equal duration.

E. Function Effects

There were no significant main effects for the musical function. The significant interactions involving function are described above.

F. Potential Issues with the Experimental Design

One challenge to this new experimental method might be that it is unnatural to ask pianists to improvise with one hand or one note at a time. While it is true that pianists usually use both hands at once when they improvise and that the ‘feel’ of musical structure is likely distributed between the hands, this does not mean that the paradigm will not still be able to test the role of motor context. Pianists are able to produce monophonic improvisations. It is not wholly unnatural to improvise monophonically and it is reasonable at least to hypothesize that single hands have a ‘feel’ for musical structure as well. However, given that significant main effects were not found between the different hand conditions for either the diatonic probability or the entropy metrics, in future experiments, such a restriction may not be necessary. A version of this experimental method could still work if the participants improvised with both hands at once.

Participants also complained in their interviews that because they were only able to play with one hand at a time, they could not change the harmony as they went along. Because the backing tracks were identical, they always were confined by the same chord voicings. This is another unnatural constriction. Outside these laboratory conditions, musicians can adapt the harmony to suit their melodic improvisations. They are in control of both. Similarly, they complained that they were unable to interact with the musicians on the backing track.

While this method does have these limitations, they were considered to be a reasonable compromise. Generally, it is not unnatural to improvise within some kind of constraint. Granted there is more flexibility outside the laboratory, there is still sufficient freedom within these laboratory constraints for the participants to improvise naturally.

Some of the pianists noted in their interviews that they ‘heard it in their ear, but could not play it with their left hand’. This may have been due to lack of facility and not a lack of cognitive access to musical knowledge. However, a lack of facility alone would not explain a reliance on diatonic pitch classes and chord tones. Further, no participants reported ‘hearing something in their ear’ that their right hand was unable to execute. This is considered further in the general discussion.

Some of the participants reported that their improvisations, particularly in the unfamiliar conditions, changed over the course of the experiment. They reported either getting better at improvising in the unfamiliar key, or ‘getting ideas’ from improvising in the familiar conditions. There may have been learning effects over the course of the experiment. The notion of being able to learn from yourself by listening to how you play under familiar conditions, or perhaps being inspired by ideas that occur in unfamiliar conditions, still supports the idea that musical knowledge is divided. This would fit with the theory behind this experiment. However, this learning effect may have influenced the latter trials of the experiment, leading to less distinction between different conditions as participants may have imitated their own improvisations from familiar conditions. This may have made effects between the hands harder to detect, but would not invalidate significant effects detected in the experiment as it is.

Some participants complained that towards the end of the experiment, they had become fatigued. A future experiment should incorporate more breaks.

Finally, pertaining to the use of the entropy calculations, a few alterations could be made in future studies. This study attempted to measure the variety of musical structures produced in improvisations. What, exactly, the ‘size’ of a structural vocabulary could mean is a bit unclear. Improvisers might have knowledge of a discrete number of structures, but they may also be generating structures extemporaneously according to a set of rules. A future analysis might use an entropy measure which looks at the occurrence of groups of notes (two or greater) and not just the predictability of single notes. This might detect the use of specific 'licks' and whether the same licks occur in different motor contexts. This approach could make more powerful inferences about such a musical vocabulary and how it is affected by these experimental conditions. This analysis, however, would require a larger body of data.

G. General Discussion

This study introduces a method to manipulate improvisation under experimental conditions while maintaining an acceptable level of ecological validity. It provides a strategy for analyzing improvisations to make inferences about cognitive processes.

This research re-informs the distinctions made between types of knowledge in cognitive models of musical improvisation. It has empirically demonstrated how musicians rely on different types of knowledge while improvising in unfamiliar motor contexts. The data from this research coupled with the subjective reports gathered from the interviews suggest particular ways these types of knowledge may be related and also suggests methods to further probe their relationship.

Jazz pianists employ different strategies depending on the context in which they are improvising. In the familiar key with the familiar motor context, the participants had auditory imagery linked with motor plans. They were able to play according to their auditory imagery. In the absence of familiar motor patterns in the unfamiliar key, improvisers used their explicit knowledge of chord tones and scales to improvise. They could still 'hear' what they wanted to play, but they did not have the motor patterns associated with those auditory images, and so could not play them. When the motor patterns and auditory imagery components were thus dissociated, they relied on declarative knowledge to choose what to play.

From this perspective, the distinction is not exactly between declarative and procedural knowledge, but instead suggests different modes of engagement with the task of improvising. In one mode, the improvisers' auditory images are linked with motor plans. They can execute motor patterns according to what they 'hear'. In the other mode, when only auditory imagery is present, improvisers instead employ a type of knowledge which may not have immediate imagery components, but which can be used to generate new, unrehearsed motor patterns. The improvisations in the unfamiliar key were likely the product of a process like this. Deliberately choosing notes, as some of the participants described it in their interviews, is not a process of accessing procedural knowledge of motor programmes. The motor behavior follows from knowledge of scale degrees and chord tones, but is distinguished from the fluent motor programmes already linked with auditory images as in the familiar key improvisations. In the unfamiliar key and motor context, improvisers use a different process of knowing, and this process has a different influence on the musical structures produced. Following the implications of the results reported here, the next logical step is to further explore the relationship between these modes of imagery.

Many of the findings of this study may be further explored in terms of expertise effects. The participants were all experienced jazz improvisers. Professional and seasoned experts, however, might show less difference between motor contexts according to the metrics used in this study. Part of being an expert may simply be developing procedural knowledge to play in uncommon keys by experience alone. However, it may also be that such experts have a different mode of engagement. Their auditory imagery may be linked with motor plans in a qualitatively different way than novices. This is another research area which could follow from this study.

Finally, this paradigm could be applied to a wider variety of improvisational behaviors. MIDI data are rich. Many other forms of analysis not used in this study could potentially be performed on data collected in a similar manner. Also, this method of collecting and analyzing data could be used in other solo improvisatory contexts. For example, pianists could improvise choruses of Rhythm Changes with both hands without a backing track. This would be a potential solution to some of the problems with ecological validity imposed by the harmonic restrictions of the backing track. Further, this method could examine how musical improvisations are affected in the presence of an audience. Nervousness precipitated by an audience may affect which improvisational mode is employed. The modes of analysis used in this study could also be used in group improvisational contexts to compare the musical content produced by different improvisers when they improvise together.

IX. CONCLUSION

This study provides a new perspective on how to distinguish between types of knowledge employed by improvisers. It reframes the question in terms of modes of engagement with improvisation dependent on the link between auditory imagery and motor patterns. It provides a method which could be used for future experiments and suggests possible lines of research following from these findings.

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